A Look-up-table Approach to Inverting Remotely Sensed Ocean Color Data

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LONG-TERM GOAL

The overall goal of this work is to develop and evaluate a new spectrum-matching technique for inverting remotely sensed hyperspectral signals to recover environmental information.

OBJECTIVES

My colleagues and I are developing and evaluating a new technique for the extraction of environmental information such as water-column inherent optical properties and shallow-water bottom depth and classification from remotely-sensed hyperspectral ocean-color spectra. Our technique is based on a "look-up-table (LUT)" approach in which the measured remote-sensing reflectance spectrum is compared with a large database of spectra corresponding to known water, bottom, and external environmental conditions. The water and bottom conditions of the water body where the spectrum was measured are then taken to be the same as the conditions corresponding to the database spectrum that most closely matches the measured spectrum. The research issues center on development and evaluation of spectrum-matching algorithms, including quantification of how various types of errors in the measured spectrum influence the retrieved environmental data.

APPROACH

The technique was first developed and tested using Hydrolight-generated pseudodata. This year, we applied the LUT technique to Ocean PHILLS (Ocean Portable Hyperspectral Imager for Low-Light spectroscopy; Davis, et al., 2002) imagery taken during the ONR CoBOP (Coastal Benthic Optical Properties) field experiments at Lee Stocking Island (LSI), Bahamas and to imagery acquired near Looe Key, Florida in October 2002.

The Hydrolight radiative transfer numerical model (www.hydrolight.info; Mobley, 1994; Mobley and Sundman, 2001a,b) gives an exact solution of the radiative transfer equation given the water inherent optical properties (IOPs, namely the absorption and scattering properties of the water body), the incident sky radiance, and the bottom depth and reflectance (bottom BRDF). The water IOPs can be built up from any number of components, such as various microbes, dissolved substances, organic detritus, mineral particles, or microbubbles. For remote-sensing purposes, the relevant Hydrolight output is the spectral water-leaving radiance or the remote-sensing reflectance.

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The first step in the recovery of environmental information from a hyperspectral image is to construct a database containing remote-sensing reflectance spectra [$R_{rs}(\lambda)$, where λ is the wavelength] from a large number of Hydrolight runs corresponding to different combinations of water composition (different microbial, dissolved, or mineral substances at different concentrations), bottom conditions (sand, seagrass, coral, etc. at various depths), sky conditions (different solar angles and atmospheric conditions), sensor viewing directions, wavelengths, and so on. The resulting spectra in the database, $R_{rs}^{d}(\lambda)$, are all unique. Given a measured reflectance spectrum $R_{rs}^{m}(\lambda)$ (obtained after atmospheric correction of an at-sensor radiance), one can then "look up" the $R_{rs}^{d}(\lambda)$ spectrum that most closely matches $R_{rs}^{m}(\lambda)$ by some criterion such as least-squares minimization over wavelength. The water IOPs and bottom conditions in the actual water body are then taken to be the values that were used in Hydrolight to generate the selected $R_{rs}^{d}(\lambda)$. We thus effect an inversion of the measured spectral reflectance signature by the conceptually simple process of spectrum matching and then looking up the answer in the database. It is important to note that we are working with calibrated R_{rs} spectra (units of sr^{-1}), not normalized or uncalibrated spectra.

WORK COMPLETED

This year's work consisted of methodology and software development and evaluation using imagery from Lee Stocking Island (LSI), Bahamas and Looe Key, FL. Representative IOPs and bottom reflectances measured at LSI and Looe Key were assembled and used (along with measured and modeled IOPs for Case 1 and 2 water) in a special version of Hydrolight to create an R_{rs} database of 19,545 spectra. These spectra were then used to process PHILLS imagery from LSI and Looe Key.

Figure 1 shows a PHILLS image of the Adderly Cut area near LSI. The figure was generated as an RGB image using 3 of the 83 PHILLS wavelengths. Figure 2 shows the LUT-retrieved bathymetry as retrieved pixel by pixel from the PHILLS image. The black lines show the path of a small boat used (by P. Reid and E. Louchard) to obtain acoustic bathymetry for comparison with the LUT bathymetry. Figure 3 shows the corresponding LUT-retrieved bottom classification.

This work does not involve the acquisition of field data. Therefore, no data have been submitted to any national data archive.

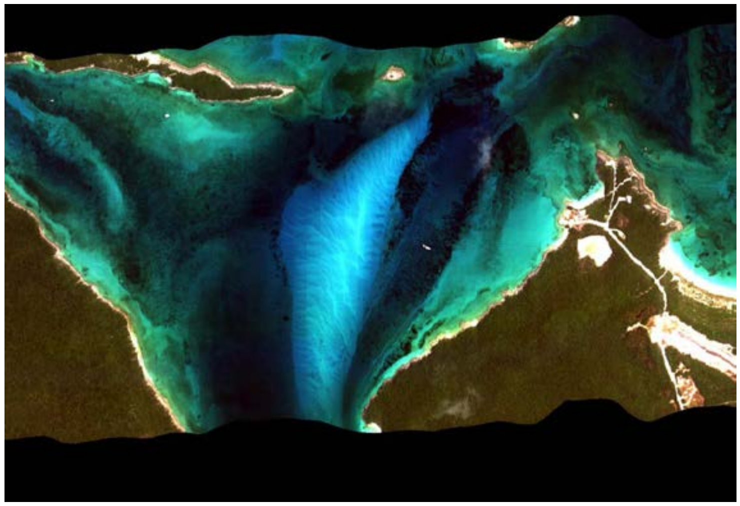

Figure 1. PHILLS RGB image of Adderly Cut, near Lee Stocking Island, Bahamas. The prominent features are an ooid sand shoal (bright area at center), sparse to dense sea grass beds (greenish areas), and coral reefs fringing the islands.

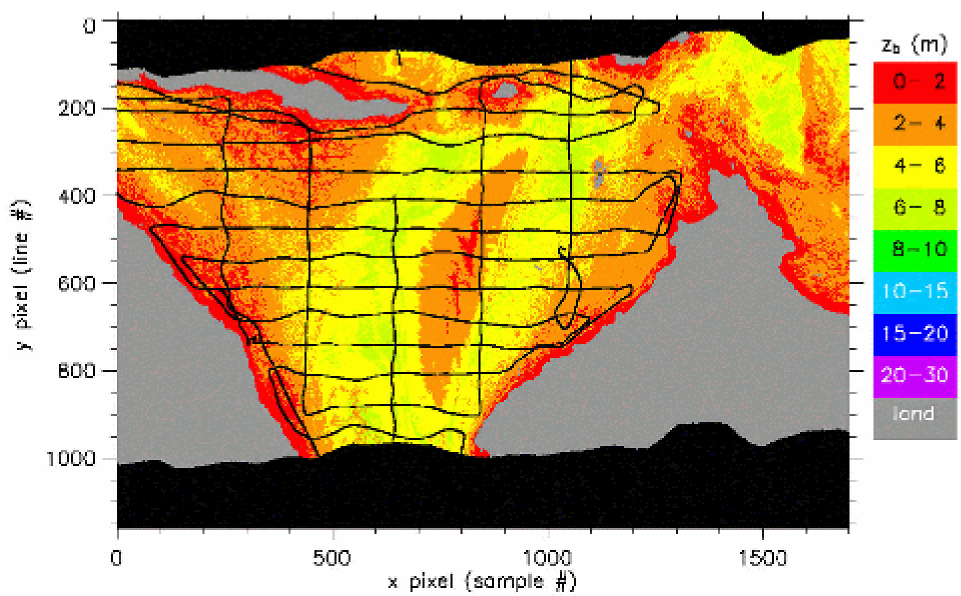

Figure 2. Bathymetry as retrieved by applying the LUT methodology to a PHILLS image of Fig. 1. The black line is the boat track used to acquire acoustic bathymetry for comparison with the LUT bathymetry.

[picture: shows a color-coded map of bottom depth near LSI. Depths range from 0 to 10 m.]

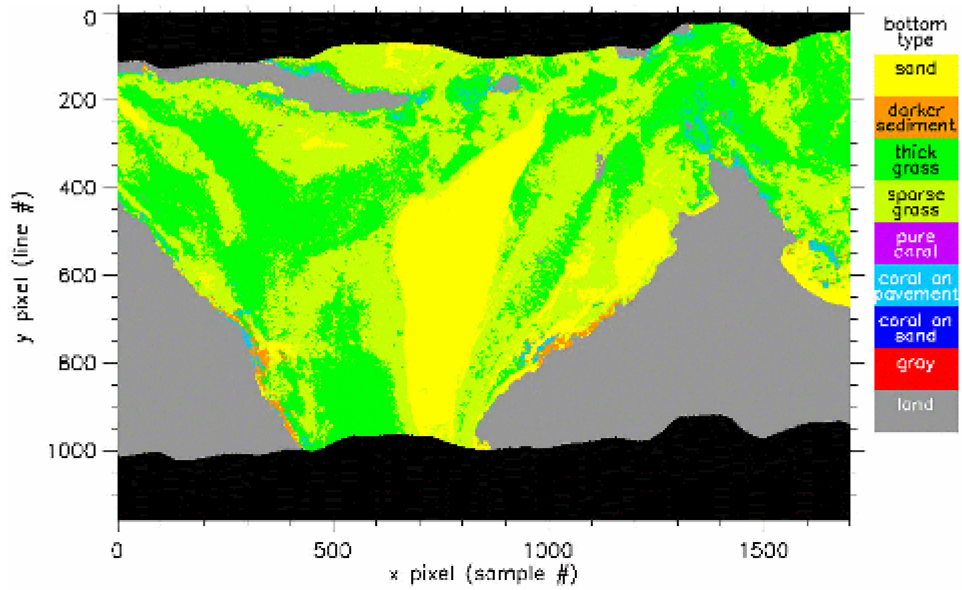

Figure 3. LUT-retrieved bottom classification corresponding to Fig. 1.
[picture: shows a color-coded map of bottom classification, such as sand, sparse or thick seagrass beds, or coral.]

RESULTS

The LUT approach to retrieving IOP, bottom reflectance, and bottom depth information from remote-sensing reflectances performed well in its initial application to various PHILLS images. However, for the image of Fig. 1, the LUT-retrieved depths were less than the acoustic depths by an average of 29%. The LUT-retrieved and acoustic depths are shown in Fig. 4.

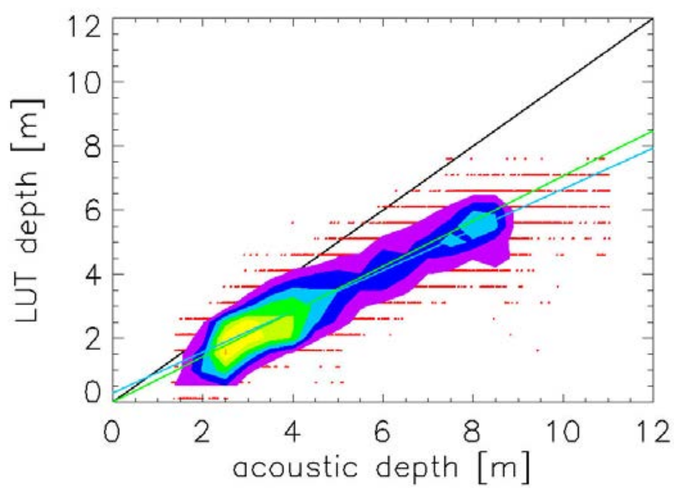

Figure 4. LUT-retrieved depths vs. acoustic depths for 20,000 pixels along the black lines seen in Fig. 2
[figure: shows a swarm of points for acoustic depth (abscissa) and LUT depth (ordinate), color coded by density of points.]

In an application to a Looe Key image, 56% of the LUT depths were within ±1 m of the corresponding depths obtained by LIDAR, and 76% were within ± 2 m of the LIDAR depth.

Some areas were misclassified as to bottom type. The reasons for these inaccuracies in depth and bottom classification is likely that the Hydrolight-generated R_{rs} database did not include bottom reflectance or IOP spectra that were representative of the actual environments seen in the PHILLS images.

The database search and spectrum matching is numerically fast. For example, the PHILLS image seen in Fig. 1 and 2 contains approximately 2 million pixels, each with 83 wavelengths. Searching the database of 19,545 spectra for each pixel and generating the bathymetry and bottom classification maps of Figs. 2 and 3 required only about one hour on a fast PC. Further run-time optimization has not yet been done. This means that near-real-time processing of PHILLS images is feasible.

IMPACT/APPLICATION

The problem of extracting environmental information from remotely sensed ocean color spectra is fundamental to a wide range of basic and applied science problems. No single inversion technique can be expected to be superior in all situations; therefore all techniques must be evaluated. In addition to investigating a new type of inversion, part of our work is to evaluate when the LUT technique is superior to other techniques, and when it is not. This work thus adds to the existing suite of remote sensing analysis techniques.

TRANSITIONS

The various databases of water IOPs, bottom reflectances, and resulting R_{rs} spectra, along with all specialized Hydrolight code and spectrum-matching algorithms have been transitioned to Dr. Curtiss Davis (NRL Code 7212) to support his exploitation of the Ocean PHILLS hyperspectral ocean color remote sensing system to retrieve bottom bathymetry and bottom classification information in optically shallow waters. The same code and database are used by P. Bissett at Florida Environmental Research Institute (FERI) for processing PHILLS-2 imagery.

RELATED PROJECTS

This work is being conducted in conjunction with Dr. Curtiss Davis and colleagues at the Naval Research Laboratory, Washington D.C., who are separately funded under Hyperspectral Characterization of the Coastal Ocean (HCCO). The PHILLS image of LSI used to generate Figs. 1, 2, and 3 were provided by NRL. The Looe Key imagery was provided by P. Bissett of FERI, who is separately funded for this collaboration (see ONR annual report OP07 by P. Bissett). The water IOPs and bottom reflectance spectra used to generate the R_{rs} database spectra characteristic of Lee Stocking Island, Bahamas were obtained from CoBOP investigators Charles Mazel, Pamela Reid, Emmanuel Boss, and Ronald Zaneveld.

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HONORS/AWARDS/PRIZES

C. D. Mobley of Sequoia Scientific, Inc. was invited to give the prestigious Riley Memorial Lecture at Dalhousie University (www.dal.ca/~wwwocean/ocean_1093.html) in September 2003. This honor is conferred each year on a scientist of international reputation by the Oceanography Dept. of Dalhousie University, Halifax, NS, Canada. Mobley discussed some of the LUT work in his presentation.